Evaluating wildfire recovery with paired field hydrology and remote sensing in Southern Sequoia National Forest

Brandon Hale[1] (bhale@ucla.edu), Alicia M. Kinoshita[1] (aliciamk@gmail.com), Terri S. Hogue[1] (thogue@seas.ucla.edu), and Carolyn Napper[2] (cnapper@fs.fed.us)
[1]Department of Civil and Environmental Engineering, University of California, Los Angeles, CA 90095, USA
[2]USDA Forest Service, Shasta McCloud Management Unit, 204 West Alma Street, Mt. Shasta, CA 96067, USA

Motivation

- Wildfire studies typically focus on immediate post-fire effects, often at the plot-scale.
- Understanding the long-term relationship between hydrology and vegetation will improve understanding of watershed recovery
  - Kinoshita et al., 2011 used remote sensing as a proxy for vegetation recovery in two burned Southern Californian watersheds; showing that coupled hydrology and vegetation recovery takes over 7 years
- Remote sensing provides coverage for monitoring extensive burn areas and variables that can be correlated to in situ hydrology
  - Clark et. al, 2012 compares Landsat vegetation indices over various burned and unburned land cover in the Western United States to plot-scale photography.

Goals

1. Couple the hydrologic effects of wildfires with vegetation recovery at a watershed scale with high temporal resolution
2. Develop a relationship between vegetation recovery and corresponding storm runoff

Fire Summaries

Fire	Location	Fire Start Date	Fire End Date	Size [mi²]	Damage
Bull	Kernville, CA	07/26/2010	08/10/2010	25.7	8 resident homes and 6 outbuildings destroyed; utility and infrastructure damage
Canyon	Lake Isabella, CA	09/06/2010	09/13/2010	9.7	utility and infrastructure damage

Study Tools

- Hydrology: In situ instrumentation within each study watershed
- Vegetation: Ground-based vegetation transects for satellite validation
- Remote Sensing: Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation indices (VI)
  - Temporal resolution: 16 days; Spatial resolution: 250 meters
  - Normalized Difference Vegetation Index (NDVI): Sensitive to green spectral signature in vegetation
  - Enhanced Vegetation Index (EVI): Reduces atmospheric interference and increases sensitivity to canopy variations
  - VI values range from 0 to 1 to indicate increasing vegetation biomass

Study Sites

Basin	Area [mi²]	Outlet Elev. [ft]	Top Elev. [ft]	Slope [%]	Precipitation Gauge	Flow Gauge
Bull #1	0.99	3,535	6,385	24	10/13/2010	09/20/2010
Bull #2	1.70	3,074	6,385	26	10/13/2010	09/20/2010
Bull #3	1.60	2,930	6,384	33	Uses same instrument as Bull #2	10/13/2010
Bull Control	1.61	3,422	8,550	32	11/24/2010	11/05/2010
Canyon	0.20	3,009	5,003	32	10/26/2010	10/28/2010

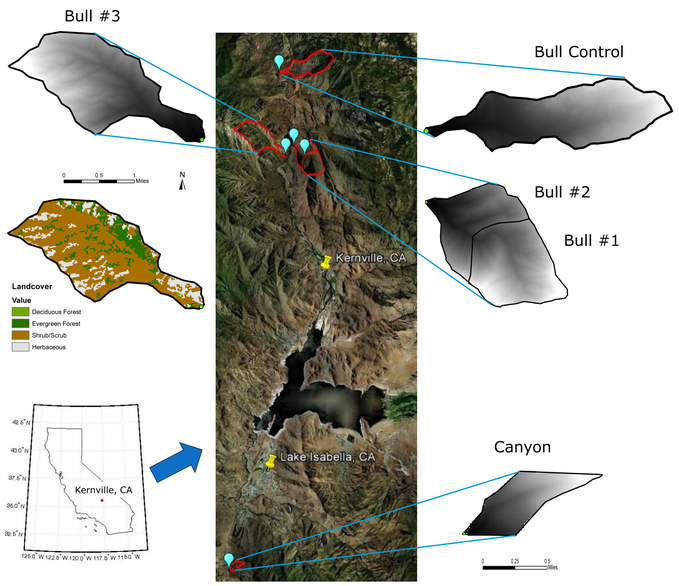


Figure 1: Relative locations and digital elevation maps for study sites (also shown: for Bull #3 (Frye et al., 2011))

Methodology

Hydrology
1. High resolution stage height
   - Rating curve
   - Manning's Eqn.
2. Cross sections
3. Event-based precipitation
   - Aggregate to 5-min. time series

Vegetation
1. MODIS Vegetation Indices
   - NDVI
   - EVI
2. Calculate watershed index average for each image (prior to each storm)

Paired Recovery Analysis
1. Identify significant storms
2. Relate vegetation index to storm runoff

Monitoring at Bull #3

Figure 2: Bull Fire #3 cross-section 5 months after burn (left) and 13 months after burn (right)

Onset HOBO pressure transducer: Records stage height at 5-minute intervals

Rainwise tipping bucket: Records events with every 0.04 inches of rainfall

Precipitation Analysis

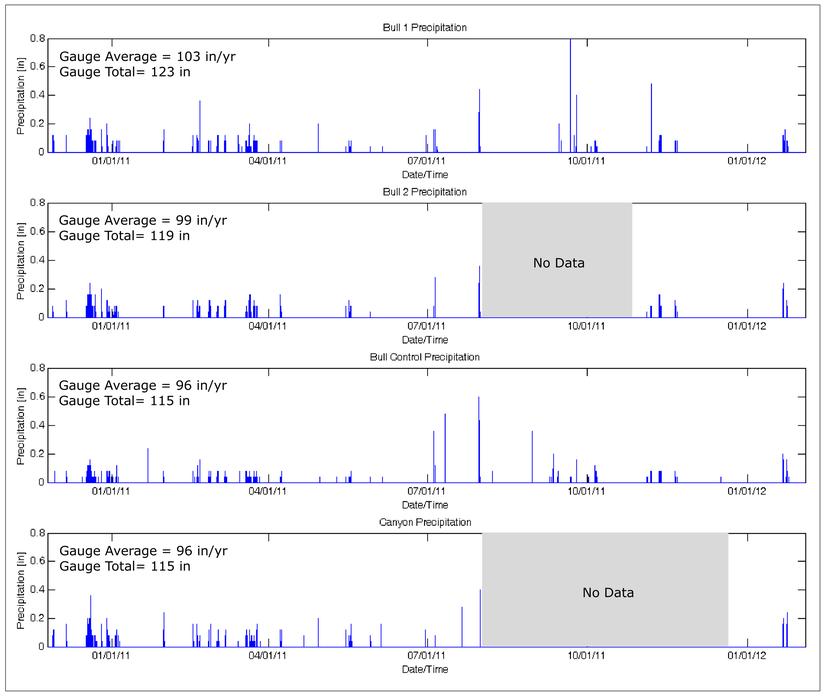


Figure 3: Precipitation time series for tipping buckets (top to bottom): Bull #1, Bull #2, Bull Control, and Canyon

Time series
- Precipitation trends are consistent between gauges
- Missing data periods will be estimated through linear regression developed between gauges

Runoff Ratios (RO)
- ROs are low immediately post-fire
- ROs increase as time between storms decreases
- Lowest ROs occur during summer months

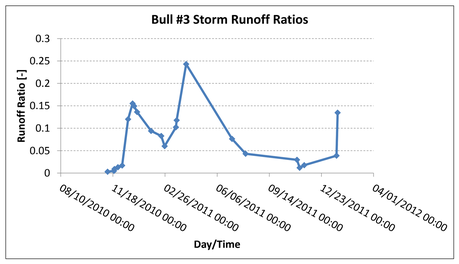


Figure 4: Bull #3 post-fire storm runoff ratios

Bull Fire #3 Hydrology

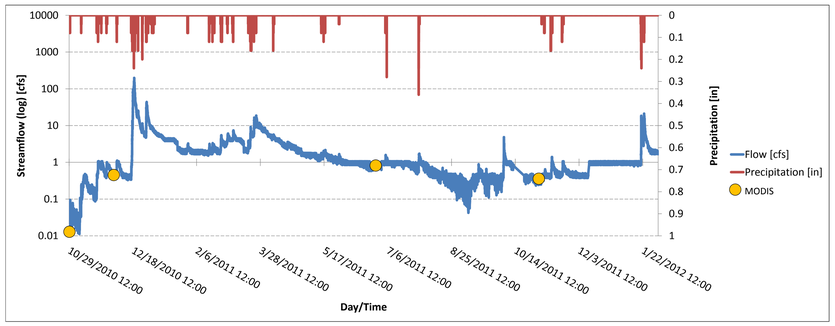
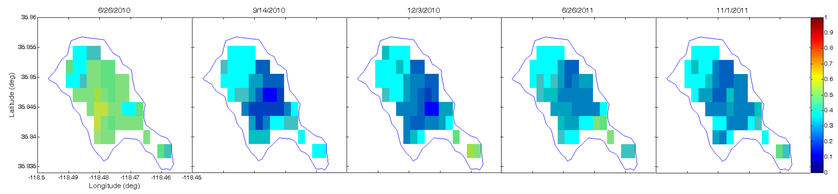


Figure 5: Bull Fire #3 streamflow (blue), precipitation (red), and corresponding MODIS image (orange)

Bull Fire #3 Vegetation

MODIS NDVI



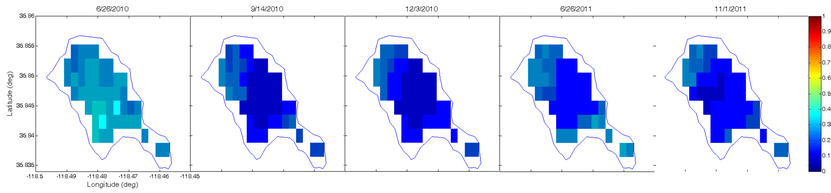
6/26/2010	9/14/2010	12/3/2010	6/26/2011	11/1/2011
Min: 0.35	Min: 0.16	Min: 0.16	Min: 0.22	Min: 0.20
Mean: 0.46	Mean: 0.32	Mean: 0.33	Mean: 0.35	Mean: 0.32
Max: 0.57	Max: 0.47	Max: 0.54	Max: 0.48	Max: 0.46

Pre-fire → Post-fire

Nearest Storm Runoff Ratio:

MODIS EVI

RO = 0.003	RO = 0.017	RO = 0.076	RO = 0.030



6/26/2010	9/14/2010	12/3/2010	6/26/2011	11/1/2011
Min: 0.19	Min: 0.06	Min: 0.06	Min: 0.11	Min: 0.08
Mean: 0.26	Mean: 0.14	Mean: 0.14	Mean: 0.20	Mean: 0.17
Max: 0.36	Max: 0.26	Max: 0.28	Max: 0.33	Max: 0.28

Figure 6: MODIS NDVI (top row), MODIS EVI (bottom row), and nearest storm runoff ratio (middle)

- NDVI does not show a significant change throughout the post-fire period
- EVI shows a slight increase in vegetation throughout the post-fire period
- Largest runoff ratio corresponds to the highest NDVI/EVI value and the lowest runoff ratio corresponds to the lowest NDVI/EVI value

Summary

Hydrology
- Post-fire RO are initially low until a significant precipitation event, indicating a precipitation threshold for higher runoff response
- RO increase as time between storms decrease (antecedent soil moisture conditions)

Vegetation
- NDVI and EVI decrease following the fire, especially in the middle of the watershed where the fire burned the hottest
- Vegetation regrowth has been highest near the outlet of the watershed (NDVI)
- Remote sensing time series data provides insight on vegetation variability

Paired Recovery
- The current MODIS resolution does not show a strong relationship between vegetation recovery and hydrologic response
- Preliminary MODIS assessment shows a need for higher resolution to capture small changes in vegetation(Landsat) and seasonal analysis

References

Clark, Jess et.al. "Utilization of satellite imagery to evaluate and predict out-year post-fire watershed response and potential application in the southwest."
Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011. Completion of the 2006 National Land Cover Database for the Conterminous united States, PE&RS, Vol. 77(9): 858-864.
Kinoshita, Alicia and Hogue, Terri. "Spatial and temporal controls on post-fire hydrologic recovery in Southern California watersheds," *CATENA*, 87(2): 240-252, November 2011.

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